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SUSY CP Problem in Gauge Mediation Model

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Supersymmetry

- SUSY is motivated by facts that SUSY ...
  - Solves the hierarchy problem
  - Preferred by gauge coupling unification
  - Provide a candidate for dark matter with R-parity

However ...

SUSY CP Problem

In terms of the CP violation, soft SUSY breaking terms can cause trouble

Dangerous sources for CP violation

this talk

K-K bar mixing, EDM

squark mass (off-diagonal)	Higgs B-term	Gaugino masses
$m_{\tilde{q}_{ij}}$	B_μ	M_A

(The phases of A-terms are also relevant)

How to generate soft SUSY breaking parameters is important

Gauge Mediation

Messenger

$$W = (M + F\theta^2)\Psi\bar{\Psi}$$

SUSY breaking

gaugino $\quad M_A \simeq \frac{g_A^2}{16\pi^2}\frac{F}{M}$

real number

sfermion $\quad \tilde{m}_i^2 \simeq \frac{1}{(16\pi^2)^2}(c_A^i g_A^4)\left|\frac{F}{M}\right|^2$

Both F and M can be taken to be real

$\boxed{\text{No CPV in gaugino and sfermion masses}}$

However, even in Gauge Mediation, new CPV phase can be induced

1. The phase of Higgs B-term

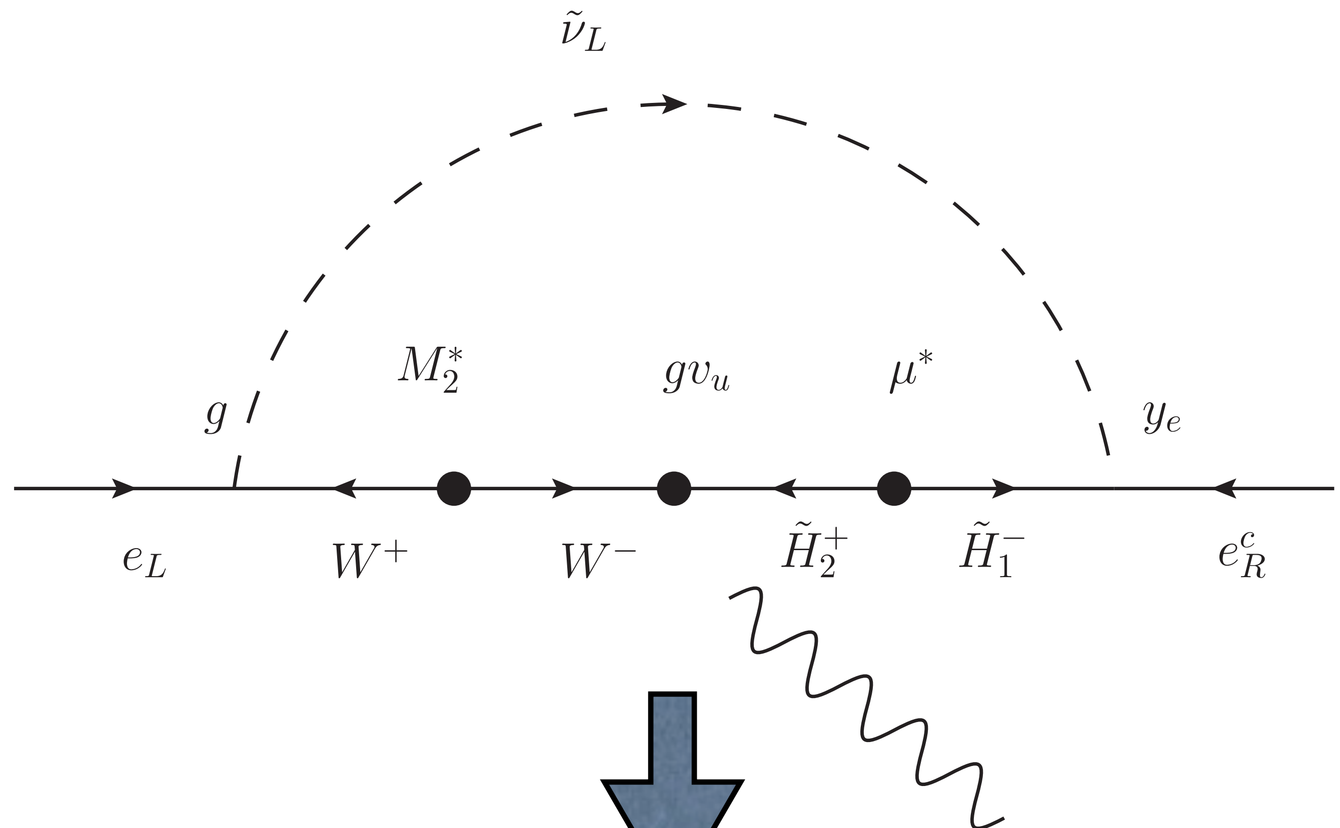
μ /B_μ problem

2. Small GUT breaking operator (Plank suppressed)

3. SUGRA effects

In this talk, we focus on 2 and 3

Electric Dipole Moment



chargino diagram is dominant

(unless higgsino and wino are heavy)

$$d_e \propto m_e \tan\beta\, \mathrm{Arg}(M_2 B_\mu^*)/m_{soft}^2$$

proportional to relative phase between Wino mass and Higgs B-term

$\boxed{\text{exp. constraint}}$

$$d_e < 2.1 \times 10^{-27} e\,\mathrm{cm}$$

(95% C.L.)

$\boxed{\text{The phase should be small as O}(10^{-3}\text{-}10^{-4})\text{ with O(1) TeV sparticles and O(10)} \tan\beta}$

Muon g-2

When sparticles are heavy the constraint on the phase becomes loose, however ....

The EXP value and SM prediction of muon g-2 are deviated more than 3 σ level

$$a_\mu^{\mathrm{EXP}} - a_\mu^{\mathrm{SM}} = (26.1 \pm 8.0) \cdot 10^{-10}$$ 3.3 σ deviation

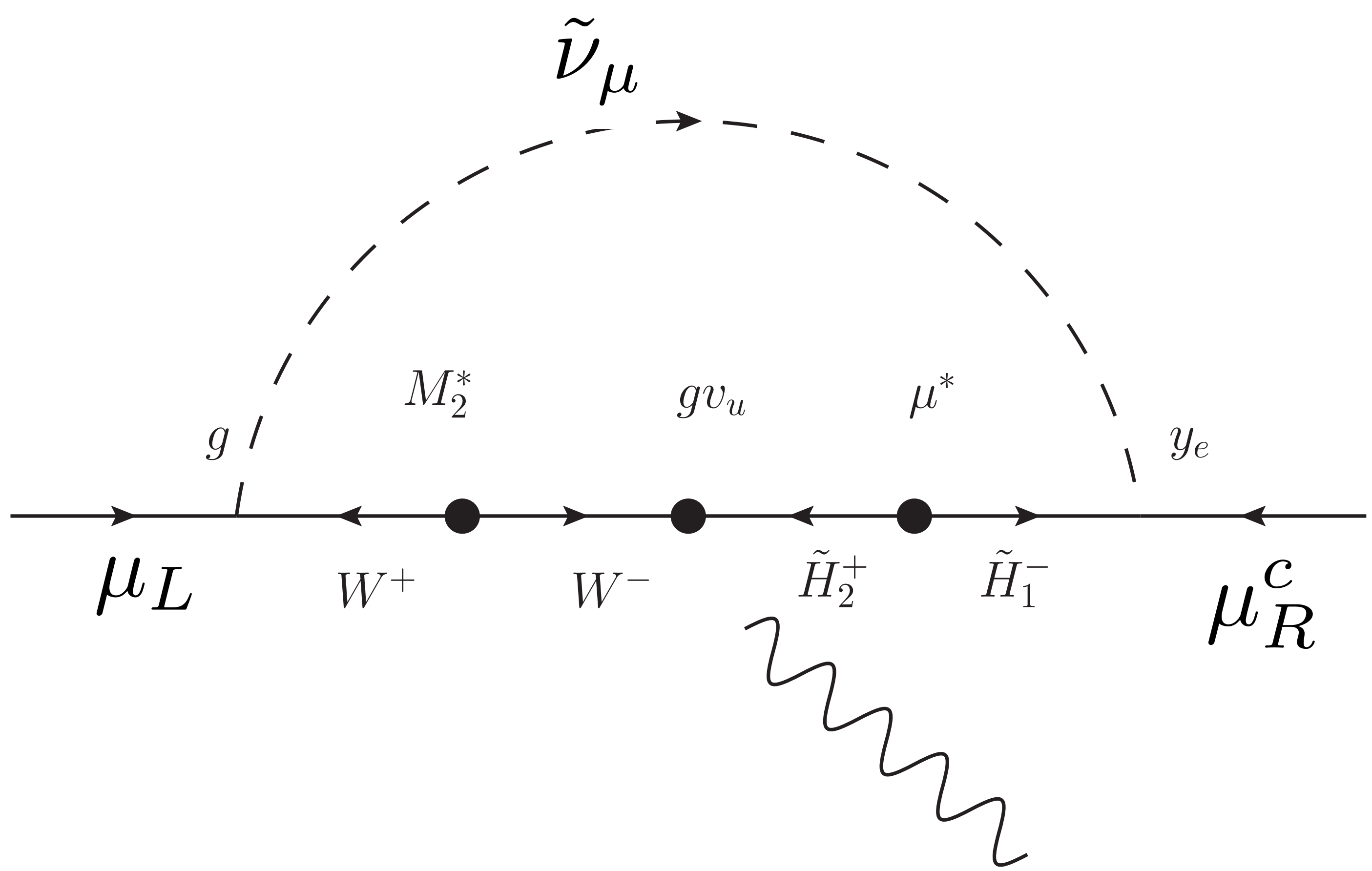
(Hagiwara, Martin, Nomura, Teubner, 2011)

The other group also reported the discrepancy more than 3 σ level

(M. Davier, A. Hoecker, B. Malaescu, Z. Zhang, 2010)

If the SUSY is responsible for the deviation of muon g-2, sleptons can not be heavy

Dominant SUSY contribution to the muon g-2 is essentially same diagram as that of EDM



$$d_e \simeq \frac{m_e}{2m_\mu^2} \mathrm{Arg}(M_2 B_\mu^*) a_\mu^{\mathrm{SUSY}}$$

(J. L. Feng, T. Moroi, 1999)

To suppress the EDM while explaining the muon g-2 is quite difficult

$\mathrm{Arg}(B_\mu)$

μ /B$_\mu$ have to be induced with the phase smaller than O(10^{-3} - 10^{-4})

(e.g.) Only SUSY mass, μ is generated above the messenger scale

$$W = \lambda \frac{X^2}{M_P} H_u H_d$$

PQ breaking scale

$$10^9\mathrm{GeV} \lesssim \langle X \rangle \lesssim 10^{12}\mathrm{GeV}$$

However, O(10^{-3} - 10^{-4}) phase can arise in other ways

The CPV effects from Dim. 5 GUT breaking operator

24 Higgs case

$$SU(5) \xrightarrow{\langle\Sigma\rangle} SU(3)_C \times SU(2)_L \times U(1)_Y$$

24 Higgs breaks GUT symmetry

$$\langle \Sigma \rangle = \frac{v_{\mathbf{24}}}{2\sqrt{15}} \mathrm{diag}(2,2,2,-3,-3)$$

Messenger

dim. 5

(The GUT breaking SUSY mass term may also exist)

$$\begin{aligned} W &= \lambda_0 S \bar{\Psi}^\alpha \Psi_\alpha + \frac{\lambda_1}{M_{\mathrm{Pl}}} S \bar{\Psi}^\alpha \Sigma_\alpha^\beta \Psi_\beta + M \bar{\Psi}^\alpha \Psi_\alpha \\ &= \lambda_0 \left(1 + \frac{1}{\sqrt{15}} \epsilon_{\mathbf{24}}\right) S \bar{\psi}_d \psi_d + \lambda_0 \left(1 - \frac{3}{2\sqrt{15}} \epsilon_{\mathbf{24}}\right) S \bar{\psi}_l \psi_l + \cdots \end{aligned}$$

$\boxed{\text{complex}}$

$$\epsilon_{\mathbf{24}} = \frac{\lambda_1 v_{\mathbf{24}}}{\lambda_0 M_{\mathrm{Pl}}} \sim \mathcal{O}(10^{-2})$$

The messengers of SU(2) doublet and SU(3) triplet have different phases of O(10^{-3})

The phases of gauginos are not aligned any more

$$M_1 = \frac{g_1^2}{16\pi^2}\left(1 - \frac{1}{2\sqrt{15}}\epsilon_{24}\right)\frac{F_S}{M}$$

$$M_2 = \frac{g_2^2}{16\pi^2}\left(1 - \frac{3}{2\sqrt{15}}\epsilon_{24}\right)\frac{F_S}{M}$$

$$M_3 = \frac{g_2^2}{16\pi^2}\left(1 + \frac{1}{\sqrt{15}}\epsilon_{24}\right)\frac{F_S}{M}$$

$\boxed{\text{complex}}$

$$\epsilon_{\mathbf{24}} = \frac{\lambda_1 v_{\mathbf{24}}}{\lambda_0 M_{\mathrm{Pl}}} \sim \mathcal{O}(10^{-2})$$

The phases differ by $O(10^{-3})$

The Higgs B-term is also affected by the phase difference of gauginos through RGE

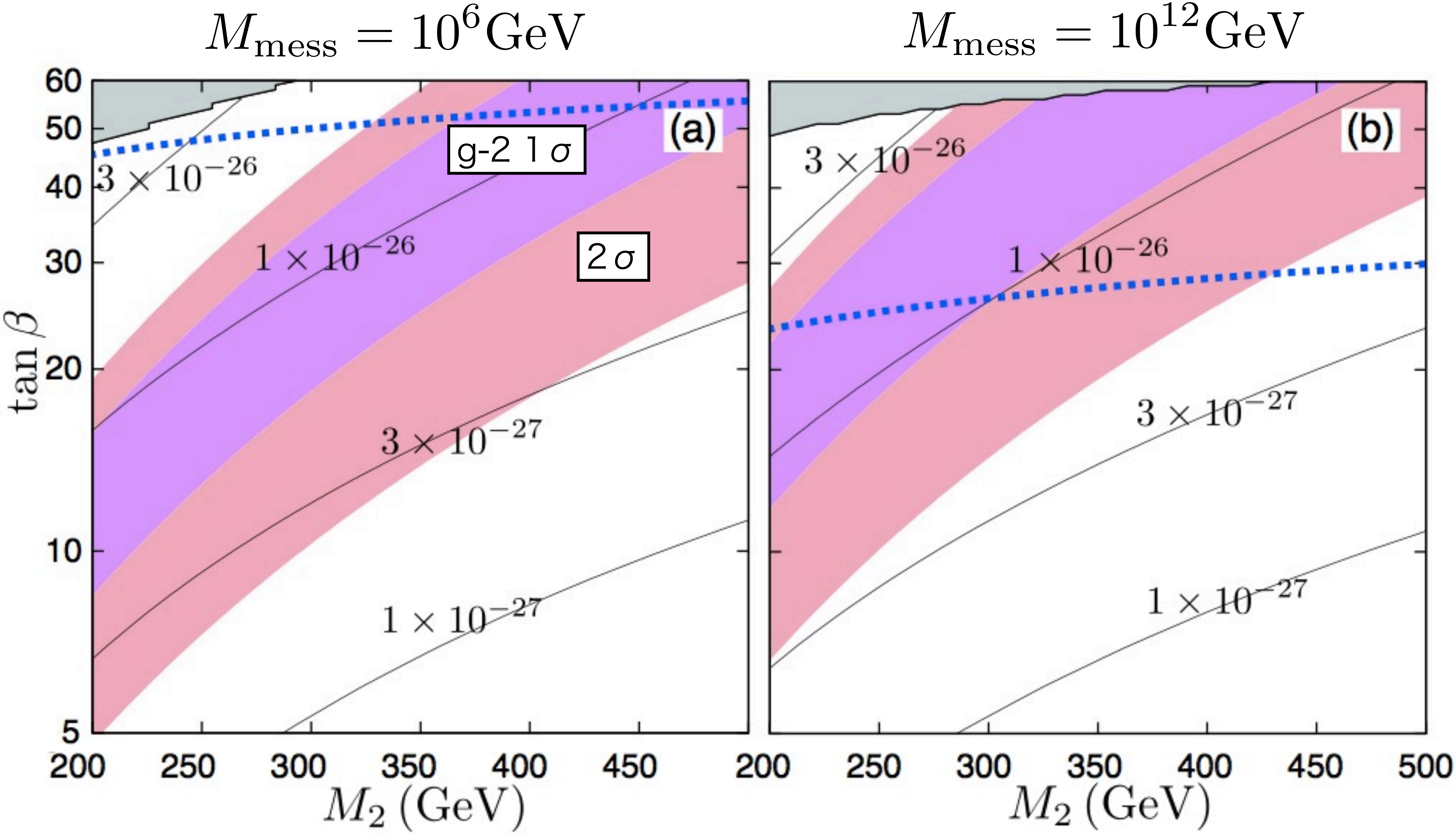
$$\frac{dB_\mu}{d\ln\mu} = \frac{1}{8\pi^2}\left[3g_2^2 M_2 + g_1^2 M_1 - 3\mathrm{tr}(Y_U^\dagger A_U) - 3\mathrm{tr}(Y_D^\dagger A_D) - \mathrm{tr}(Y_L^\dagger A_L)\right]$$

$O(10^{-3})$

$$d_e \propto m_e \tan\beta\, \mathrm{Arg}(M_2 B_\mu^*)/m_{soft}^2$$

The induced CP phase is large enough to be constrained from EDM experiments

for numerical calculation $\epsilon_{\mathbf{24}} = i0.01$



The dim 5 GUT breaking operator should be suppressed by O(0.1) somehow

exp. bound $d_e < 2.1 \times 10^{-27} e$ cm (95% C.L.).

The CPV effects from Dim. 6 GUT breaking operator

75 Higgs case

$$SU(5) \xrightarrow{\langle\Sigma\rangle} SU(3)_C \times SU(2)_L \times U(1)_Y$$

Messenger

dim. 6

$$W = \lambda_0 S\bar{\Psi}^{\alpha}\Psi_{\alpha} + \frac{\lambda_1}{M_{\rm Pl}^2} S\bar{\Psi}^{\alpha}\Sigma^{\gamma\delta}_{\alpha\epsilon}\Sigma^{\beta\epsilon}_{\gamma\delta}\Psi_{\beta} + M\bar{\Psi}^{\alpha}\Psi_{\alpha}$$

$$\epsilon_{\mathbf{75}} = \frac{\lambda_1^{1/2} v_{\mathbf{75}}}{\lambda_0^{1/2} M_{\rm Pl}}$$

$$M_A = \frac{g_A^2}{16\pi^2}(1+\kappa_A^{(\mathbf{75})}\epsilon_{\mathbf{75}}^2)\Lambda,$$

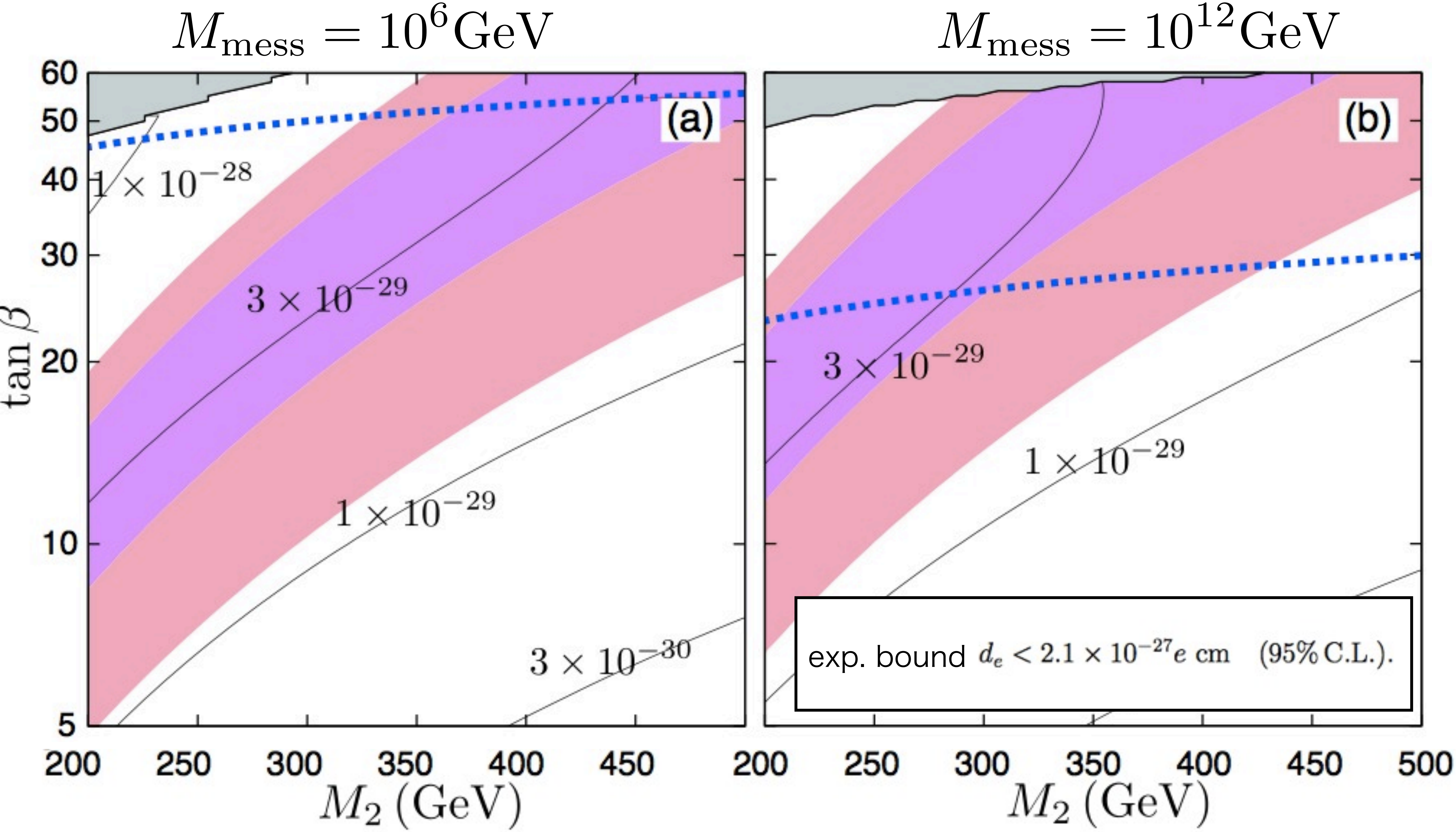
$$\kappa_1^{(\mathbf{75})} = \frac{11}{60},\ \kappa_2^{(\mathbf{75})} = \frac{1}{4},\ \kappa_3^{(\mathbf{75})} = \frac{1}{12}.$$

The induced CP phase

O(10-5)

$$d_e \propto m_e \tan\beta\, \mathrm{Arg}(M_2 B_\mu^*)/m_{soft}^2$$

for numerical calculation $\epsilon_{\mathbf{75}} = i0.01$



The dim 6 GUT breaking operator is consistent with g-2 and EDM

EDM may be seen at the future experiment

The SUGRA effects

- Even in GMSB, the effects from SUGRA exists

- Higgs B-term obtains additional contribution from SUGRA

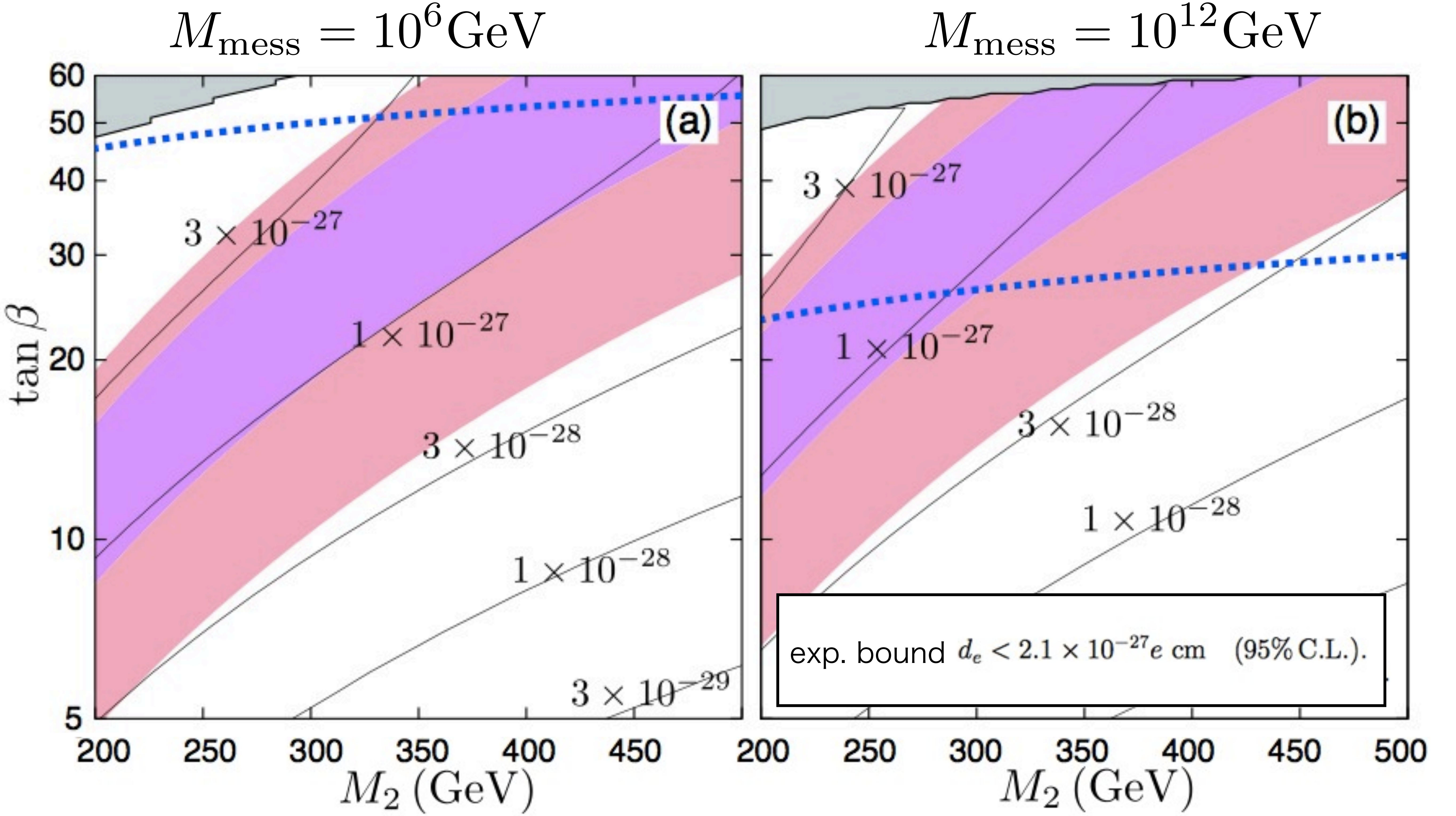
complex

$$B_\mu = B_\mu^{(0)} + B_\mu^{(\mathrm{SUGRA})}$$

$$B_\mu^{(\mathrm{SUGRA})} \sim m_{3/2}$$

For numerical calculation, we take

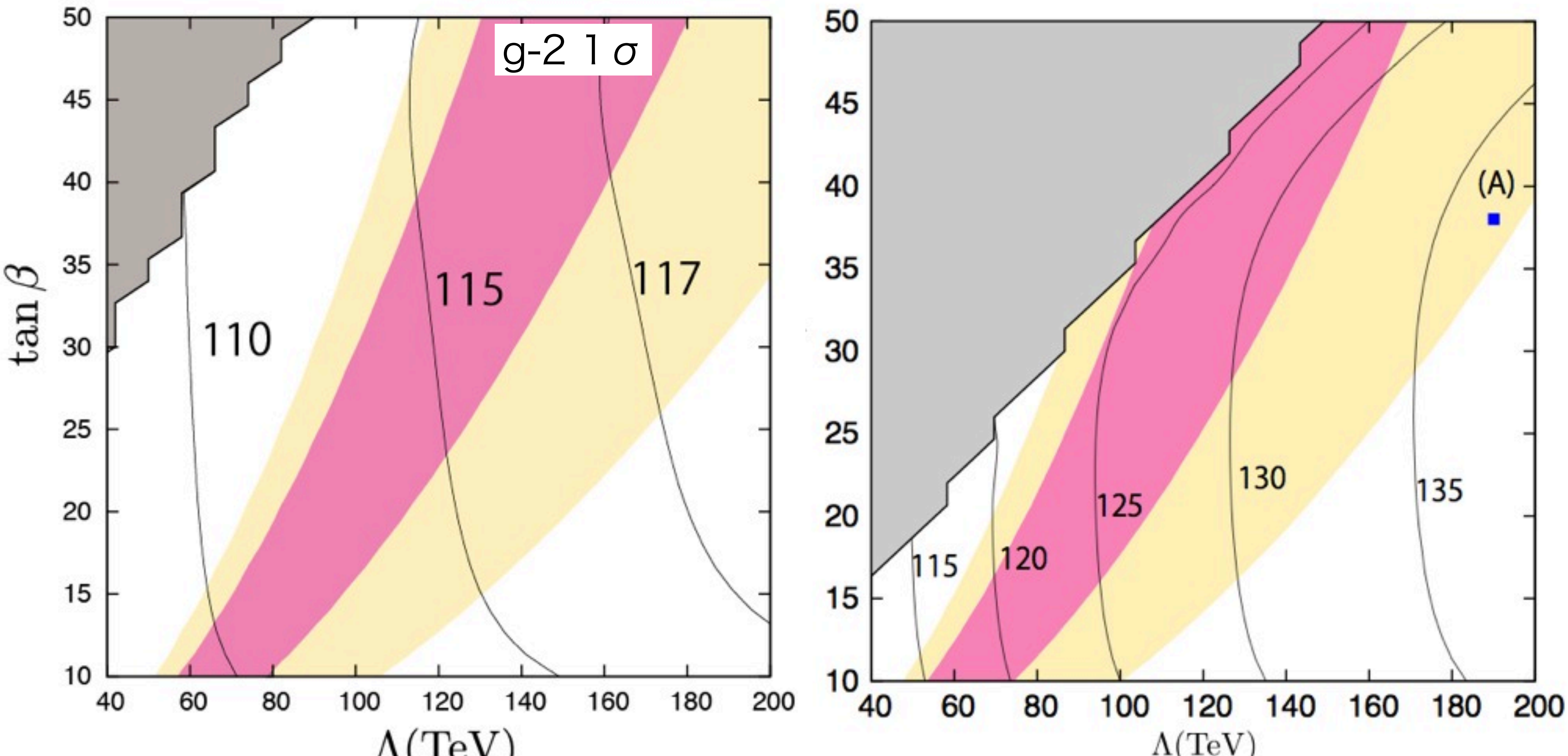
$$B_\mu^{(\mathrm{SUGRA})} = i100\mathrm{MeV}$$



100 MeV gravitino is marginally consistent with g-2 and EDM

Higgs mass in minimal GMSB

$M_{\mathrm{mess}} = 5 \times 10^5 \mathrm{GeV}$ and $N_5 = 1$



MSSM

With extra vector-like matter

(M. Endo, K. Hamaguchi, S. Iwamoto, N. Yokozaki, 2011)

Summary

- The effects of the GUT breaking operator is sizable, and may induce large EDM
- The effect of gravity mediation is also sizable when the gravitino mass is large as 100MeV
- EDM may be seen at future experiments